Acoustic Materials and Metamaterials
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Lecture – 20
Perforated Panel Absorbers

Welcome to lecture 20, the last lecture of this week 4 and today we will study about Perforated Panel Absorbers. So, we have already discussed about panel absorbers or panel resonators and this is a enhancement to that; this is a new form of absorber. So, we will study about its working and its principle. So, let us begin our discussion. So, what is a perforated panel absorber?

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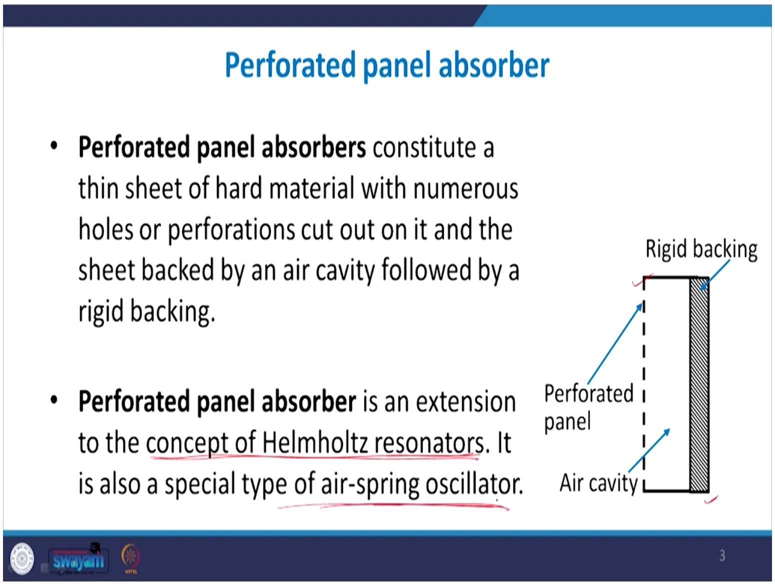

So, if you look at a figure here; so, if you look at this figure what you see is that usually, it consists of this system where you have a thin panel; it is backed by some rigid cavity. So, you studied about fixed acoustic panels with concealed cavity. So, a perforated panel is same as that with the only difference being that now the panel is not solid, but it has got holes throughout. So, it is a perforated panel.

So, this is the typical construction. So, we have a rigid backing here. So, a box with a rigid backing and this is the concealed air cavity and then this is the panel or the perforated panel with holes at regular intervals. So, this perforated panel also works on the concept of Helmholtz resonator. Therefore, it is also a special type of air spring oscillator. Let us see how.

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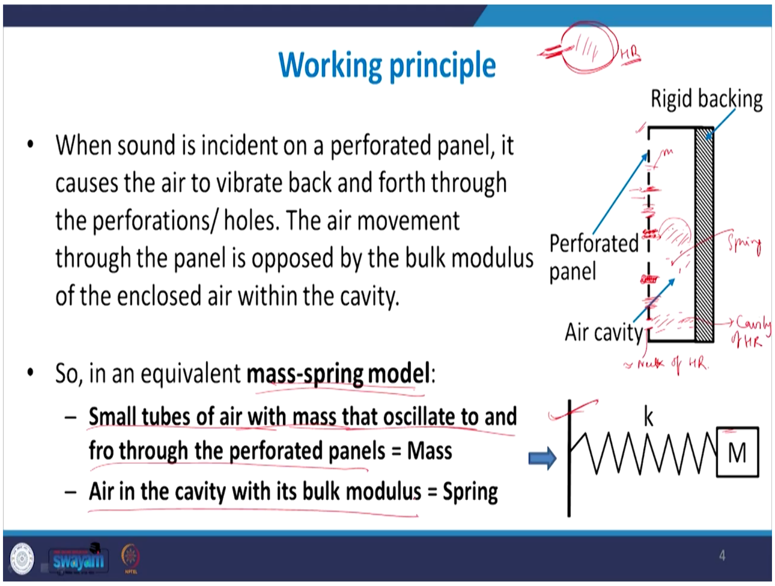

So, what happens is that here let us; now what you can imagine here is that when we had the Helmholtz resonator so, it was like a neck and a cavity that is enclosed behind the neck. And the air would oscillator about the neck and this would act as the restoring element. So, that was a Helmholtz resonator.

So, in the same principle what you can, but Helmholtz says had certain limitations. For example, the first limitation was that it can only provide for a selective frequency and then building such kind of tubes everywhere is; obviously, difficult to install and construct at any location. So, they can be difficult to construct and install. So, as an enhancement to that this perforated panel came about so, we have the individual holes in the panel, they can be assumed as the neck.

So, this is like similar to the neck of a Helmholtz resonator and the air cavity that is behind this neck on this particular air cavity, then becomes the cavity of the Helmholtz resonator. So, every hole with its corresponding cavity behind it together they constitute a individual Helmholtz resonator. And as you can say the cavity it is confined so, it is like a spring element.

So, the same logic whenever a sound wave is incident, then it will drive the air molecules here. These air molecules will start to oscillate at their fundamental frequency and when they start to oscillate at the fundamental frequency, then they will oscillate back and forth at large amplitude. So, they oscillate back and forth at very large amplitudes. And this air as they go towards the cavity, the air inside it undergoes compression and as they go out of the cavity, the air goes expansion. And therefore, due to the resistance to compression or expansion or rather to say due to bulk modulus of this particular air cavity; it acts as a restoring elements. So, it becomes like a mass spring oscillator with mass being.

This mass spring; in this particular case, the mass spring model these small tubes of air with the mass that they oscillator to and fro through the perforated panel. So, all these the mass of air that is oscillating to and fro through the panels. The mass of air oscillating through it this becomes like the mass element and the air contain with within the cavity becomes this spring element the air in the cavity. So, the perforation and the cavity behind it together they become an individual Helmholtz resonator.

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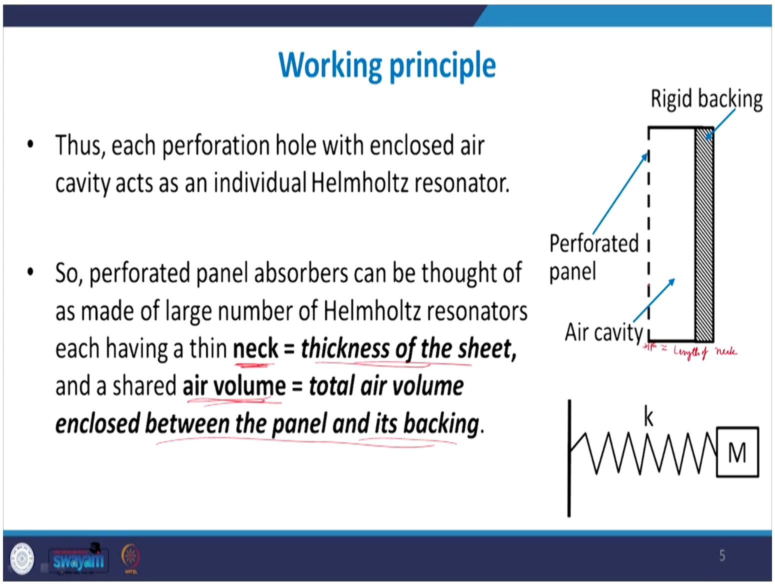

So, as already explained, here we can assume every individual perforation as a neck with a cavity behind the neck. So, here neck is equal to; so, because we have assumed this as the neck. So, the length of the neck will be the thickness of the sheet. This is a small; this is a small thickness. So, this is almost equivalent to the length of the neck of the individual Helmholtz resonator, very small length neck. And the air volume that is just behind it. So, the air volume enclosed behind the perforation and the backing then becomes the volume of the cavity.

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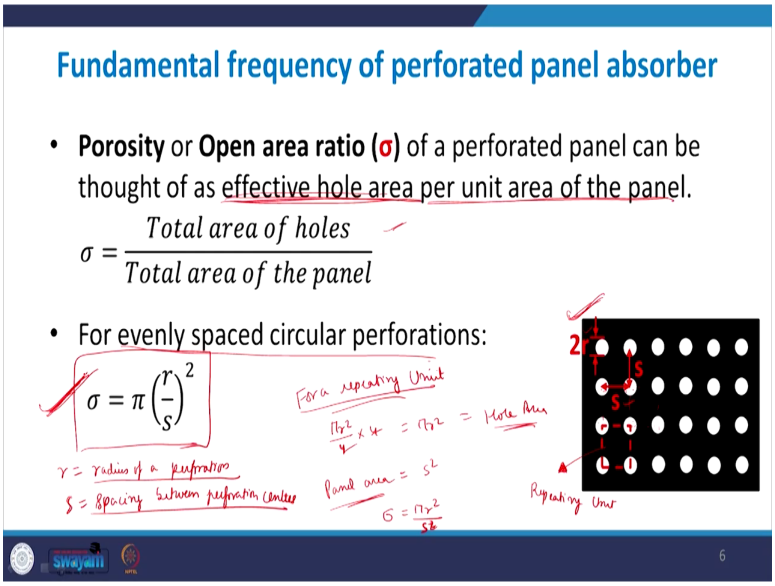

So, here we define how to define the perforations of a cavity. So, there should be some terminology by which we can say this is how the panel is being perforated. So, the very common terminology that is used is called as an open area ratio or porosity.

So, how porosity is defined is that if we have a look at this figure here. So, in this particular course we are only studying about the evenly spaced perforation. So, the holes that are made, they are even in the radius and they are in they are evenly spaced out. So, if you have a look at this particular figure here so, this is all circular holes evenly spaced and the distance between the center of two spaces s. So, s is the spacing and r is the radius of the hole.

So, sigma or the porosity or the open area ratio is, the it is the effective hole area per unit area of the panel which is also equal to what is the if you take a material, then what is the total area of the holes divided by what is the total area of the material or the what is the total area of the panel will give you what is the porosity. So, what percentage or rather what fraction of the area of the panel is being occupied by the holes; that is called as a porosity or open area ratio.

So, it can also be thought of is what is the effective hole area per unit area of the material. So, let us assume this as one unit, this is a repeat repeating unit. So, as you can see for such a large material with so, large amount of perforations. If this unit is repeated again and again, it is repeated here and then it is repeated here and then it is repeated here. So, repetition of this unit all throughout generates the panel this particular unit when it is it can be replicated here so, on the right hand side, on the top side, on the on this side.

So, if this unit is repeated in all the directions, we get the overall perforation. So, this is the common repeating element that we have taken. So, if we take this common repeating element so, within that element what is the total hole area? It is one-fourth off. It is going to be the total area of holes will be so, pi r square is the total area of a hole and every corner we have only one fourth of that and therefore, such holes.

So, it comes out to be pi r square within this repeating unit. And what is the total area of the material or the what is the total area of the panel? The total area of the panel comes out to be this. So, panel area is this and this is the whole area for a repeating unit. So, we have taken a common repeating unit and we have found what is the whole area and what is the panel area then dividing them together pi r square by s square.

So, sigma will come out to be pi r square or the total area within that unit divided by the total area of panel within that unit. So, this is the expression of sigma that we get for circular perforations that are evenly spaced out. Here r is radius of a perforation and s is the spacing between the perforation centers. What is the spacing between these perforation centers? So, this is the spacing and this is the radius.

So, this is the expression for sigma which is pi r by s whole square ah. So, as we as I explained to you every perforation can be assumed to be a Helmholtz resonator and let us see we have even perforations. So, every perforation will have the same fundamental frequency. So, we can calculate that particular fundamental frequency so, using the analogy of the Helmholtz resonator.

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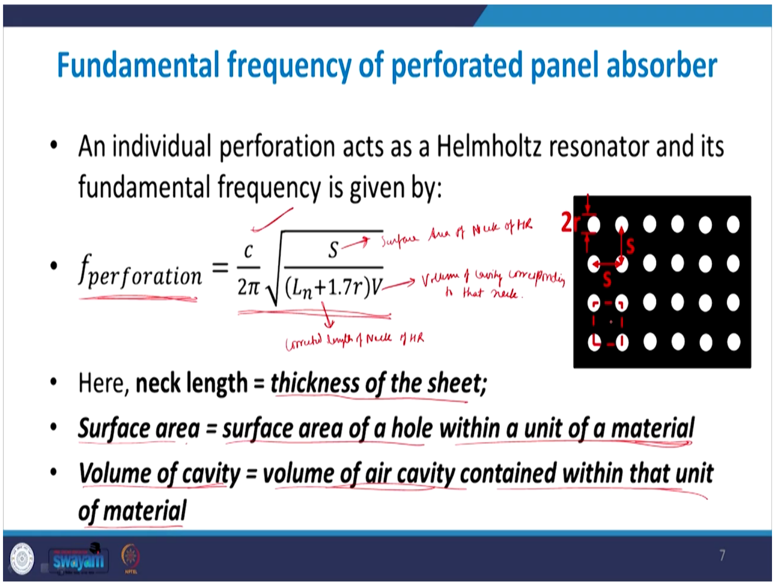

For a Helmholtz resonator, this was the fundamental frequency c by 2 pi into S. Here S was the surface area of the panel of the resonator; let us say. So, it was the surface area of the neck and this was the corrected length of the neck; so, of the neck of the resonator. So, this was for a Helmholtz resonator and this was the volume of cavity corresponding to that Helmholtz corresponding to that neck.

So, this is once the fundamental frequency for a Helmholtz resonator. Now, here the length of the neck or this L n is same is same as the thickness of the sheet. So, here this particular panel is acting as a Helmholtz resonator. So, this is like the neck and the length of the neck will simply be the thickness of the sheet and the surface area will be the area of the hole so, because every hole is a perforation.

So, we will do the average. So, in the average, the surface area will be what is the surface area of a hole within a unit of this repeating unit of a material. And the volume of the cavity would be the volume of the air cavity that is contained within that particular repeating unit of the material. So, again we are taking this repeating unit and within that we are saying what is the total area of air cavity and what is the total area of the hole or the opening which is given to us.

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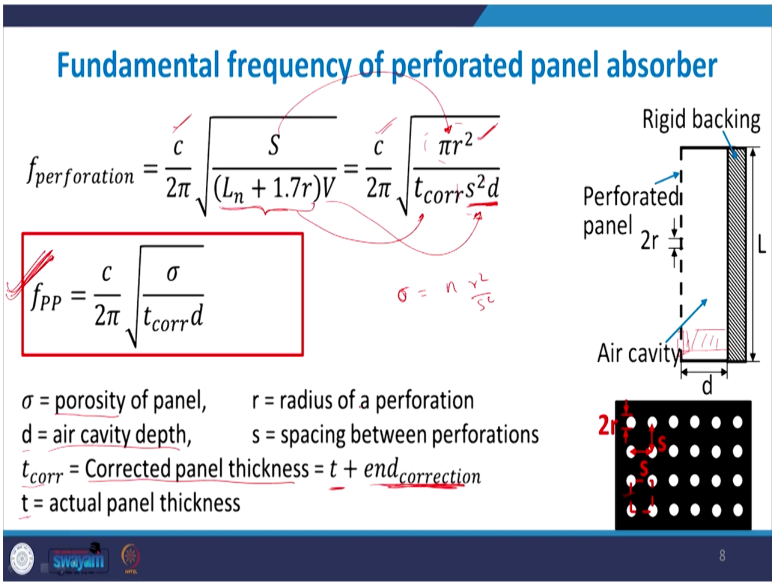

So, with this what we see is that this is the expression for a Helmholtz resonator when we make an and the locus comparison c by 2 pi and the net surface area enclosed. So, the net surface area of the neck opening is simply the net area of the hole. So, the net area of this neck opening is simply pi r square within this repeating unit.

So, it is one-fourth of pi r square multiplied by 4 and the net volume of the air cavity will be the surface area multiplied by the depth of the cavity. So, if there is some repeating unit here, then whatever is the surface area multiplied by this depth we will give you the total volume of the cavity within that repeating unit. So, it becomes d which is the depth of the cavity and the total surface area that of this particular material. So, it becomes s square times of this.

So, now this particular thing, this is the length of the neck. This is replaced by; so, this is the corrected neck length which is replaced by a corrected panel thickness because it is the panel thickness which is the neck length here. And this is the surface area of the repeating unit multiplied by d which gives us the net volume. So, this corresponds to the volume and this is or the effective opening of the neck is the effective hole area which is this one.

So, within this repeat and this is the repeating unit which repeats and the entire material is generated and for every repeating unit we will have the same fundamental frequency. So, for the overall you know overall material the fundamental frequency will be the same as the fundamental frequency for a unit a unit a repeating unit.

So, the total fundamental frequency of a perforated panel will be c by 2 pi. If you take this sigma was pi of r square by a square right. So, this entire thing becomes a sigma or the open area ratio t corrected into d. So, this is a very important formula. So, this is the formula for the fundamental frequency of a perforated panel; sigma being the porosity or the open area ratio of the panel, d is the air cavity depth and t corrected is the corrected panel thickness which can be given by the panel thickness plus the end correction. And from the table that was given in the chapter on Helmholtz resonator, you can find out what will be the approximate correction factor.

So, all this is given to us. So, we can find out the fundamental frequency of a perforated panel. So, let us solve a few problems with respect to this panel absorber perforated panel.

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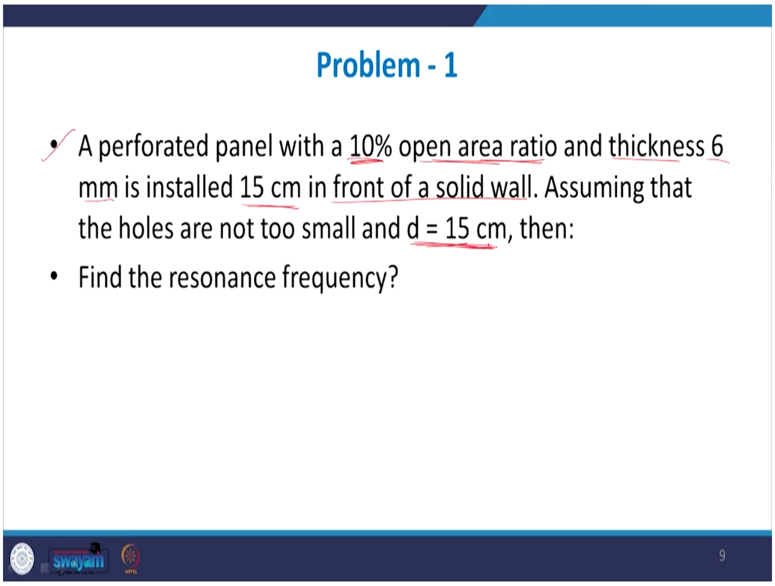

So, we have a perforated panel is given to us 10 percent is the open area ratio and thickness is given as 6 millimeters and it is installed 15 centimeters in front of a solid wall.

Assuming that the holes are not too small d is given. So, d here is what it is same as the distance between the panel and the solid wall which is 15 centimeters and you have to find the resonant frequency.

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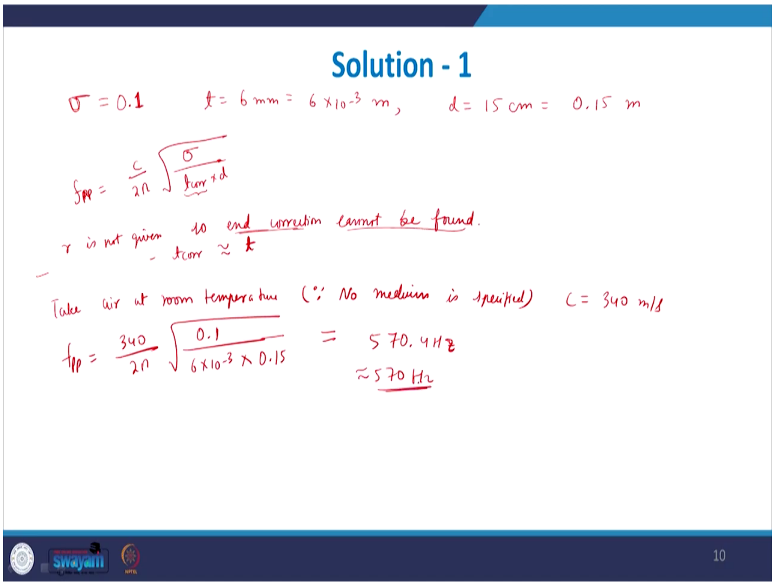

So, all these values are given to us. Let us write down these values sigma is given to us or the open area ratio is 10 percent. So, infraction it will be 0.1, thickness is given of the panel is 6 millimeters which is 6 into 10 to the power minus 3 meters.

And the d is fifteen centimeter which is going to be 0.15 meter. So, everything I have written in SI unit. Then the natural frequency of this resin perforated panel will be c by 2 pi under root of sigma divided by t corrected in to d because radius is not mentioned to us here. So, r is not given to us r is not given. So, end correction cannot be found because n correction is some factor of r.

So, whenever insufficient data is given when in that case we simply take the actual thickness as a thickness because we do not know what the end correction factor is going to be. So, in that case the solution so, we take t equals two therefore, we take t corrected approximately same as the thickness of the panel because n correction is not cannot be found without an incomplete data; without incomplete data it cannot be found.

So, we have to find the resonant frequency which comes out to be; now again taking air at room temperature ok. So, let us t; again no medium is specified to us. So, we take air at room temperature ok, it is forgetting a bit congested; let me rewrite it. So, we have now we take air at room temperature because no medium is specified. Since no medium specified so, we take the common medium here.

So, what we get is then c becomes 340 meters per second. So, the resonant frequency will be 340 by 2 pi you putting all the values given to us. t is 6 into 10 to the power minus 3 multiplied by 0.15. So, what you get is approximately 570.4 Hertz or approximately 570 Hertz.

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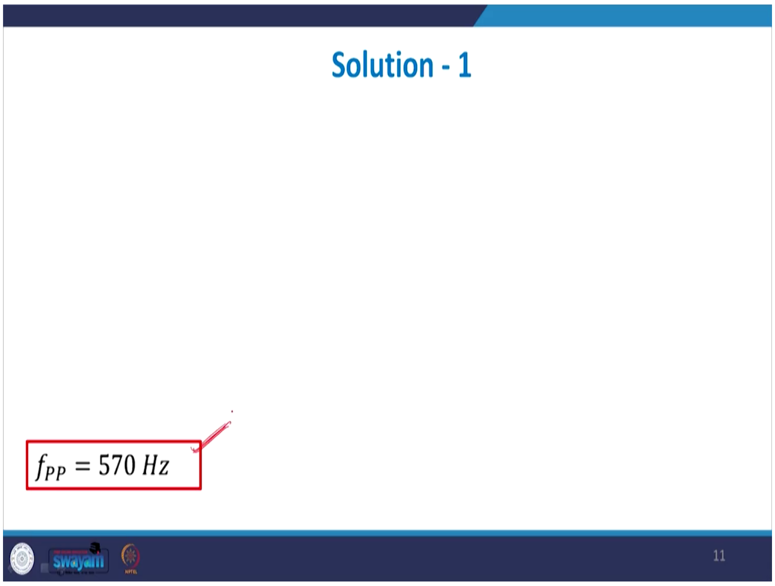

So, that is a solution for this particular panel.

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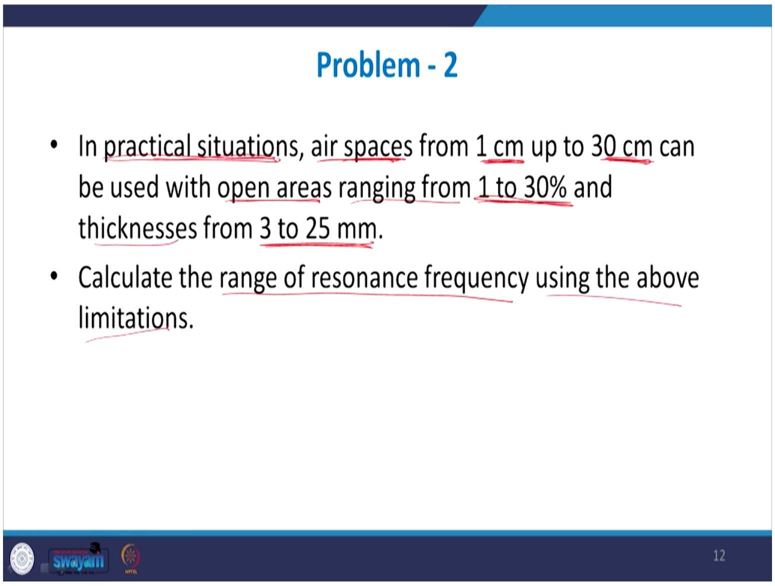

Let us solve another problem. So, constructing the so, ideally any kind of mp perforated panels can be constructed with any value of cavity depth or any value of porosity and any value of panel thickness. But usually there are limitations; for some limitations are because of the physics of the physics or the fundamental limitation of the material itself in the equations and then some limitations are due to manufacturing. So, many such limitations are imposed and due to that in practical situations.

It is given that the airspace is from 1 centimeter to 30 centimeter can be used. So, these this is the practice in general manufacturing limitations etcetera they dominate. So, this is the limitation on the airspace depth and similarly they can be used with open areas ranging from 1 to 30 percentage and thickness from 2 to 25 millimeters. So, the practical range of d sigma and t is given to you. You have to calculate then what is the range of the resonance frequency using this above limitations.

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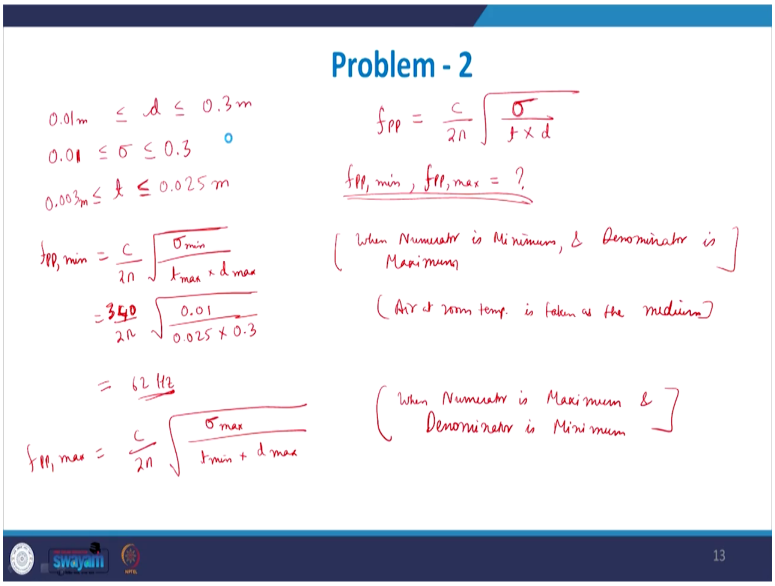

So, let us first write down the limitations. So, here the airspace can be somewhere between 1 centimeter to 30 centimeter. So, I am going to write everything within the SI unit. So, it will be 0.01 meters to 0.3 meters is the d, sigma is given as 0.01 or 1 percentage to 30 percentage which is 0.3 and d is given as.

So, sigma of higher values can be constructed, but in this particular problem some manufacturing limitation has been imposed and certain limitations are given, but they are not the case everywhere. So, only for this question these are the limitations. So, this thickness is somewhere between 3 millimeters to 25 millimeters. So, I have written everything within the SI unit. So, I have written all this and we know that the f pp or the frequency resonant frequency of the perforated panel is c by 2 pi under root of sigma by again radius nothing about the radiuses mentioned. So, we will simply take is at t multiplied by d.

So, and we have to find what is the range of minimum and the maximum what is the range of the frequencies. So, f minimum f pp minimum and f pp maximum has to be found to find what is the range of practical frequencies that can be obtained. Now f, p p when will f p p be minimum? If we look at this equation f p p, we will be minimum when the numerator is maximum and the denominator.

So, f pp will be minimum when the numerator is minimum when numerator is minimum and denominator is maximum, then we will get the minimum value of f pp. So, f pp will simply be c by 2 pi. You take the minimum value of the numerator which is the minimum value of this and the maximum values of this and put it together. Again we take air at room temperature air at room temperature is taken is taken as the medium.

So, we take this value is 340 ok. So, everything by calculating for air at room temperature; in certain questions some other medium can be specified and then you will have to use the speed of sound corresponding to that medium. So, if you use this value here and put the corresponding value so, the minimum value of sigma you put and the maximum value of the thickness and the maximum value of this depth. Then what you get is somewhere close to; so, what you are getting is somewhere close to about 62 Hertz.

And when you do the same thing for f pp max, it will be c by 2 pi you this for maximum value. This you take as maximum and the denominator you take as minimum to get the maximum value of this. So, this is when numerator is maximum and denominator is minimum. So, f pp is maximum here.

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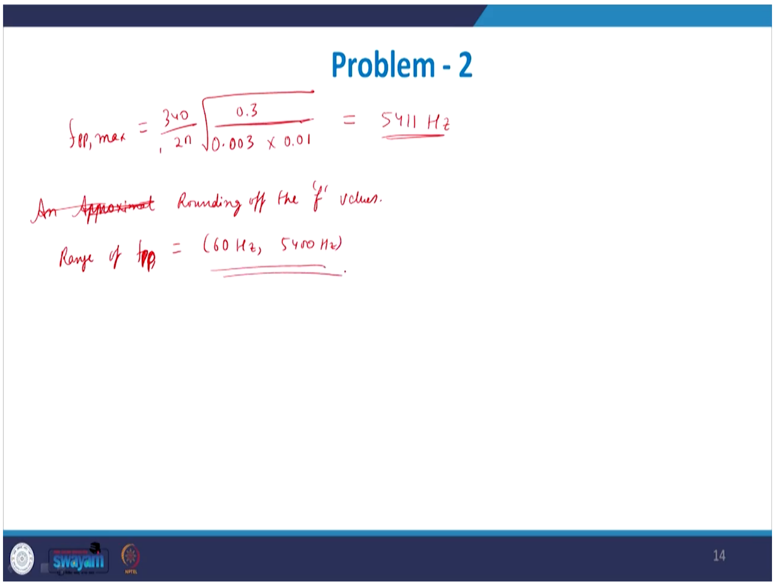

So, if you take these values then f pp max will be 340 by 2 pi. You take the maximum value of sigma which is 30 percent or 0.3 and the minimum values of t and d respectively which comes out to be; if you see here it is 0.003 and 0.01.

So, 0.003 and 0.01. So, this when you calculate this particular value so, what you get is somewhere close to 5411 Hertz. So, an approximate range can be given. So, let us just approximate or rounded of range or let us say rounding of the frequencies rounding of the f values. What we get is the range becomes the range of the resonant frequencies or the range of f pp becomes between 60 Hertz to 5400 Hertz and so on.

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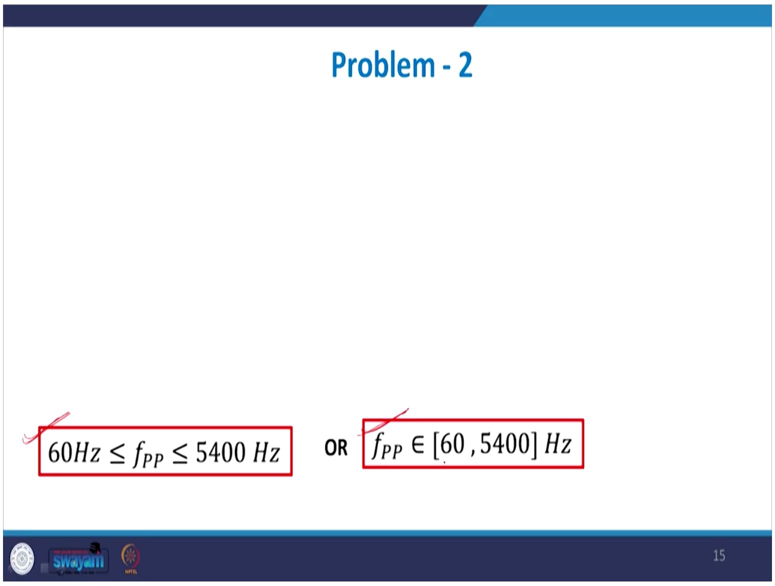

So, that becomes our range, you can either express it like this or you can express it in this form. So, it is an element within this particular interval.

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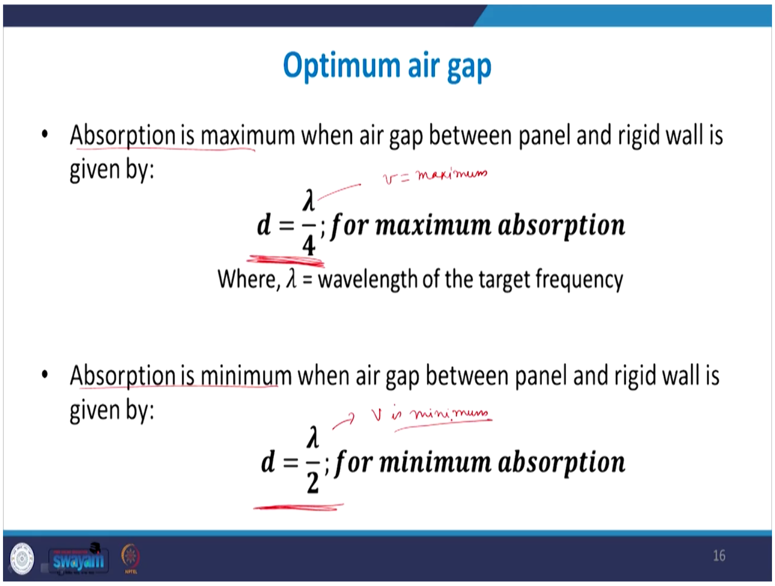

So, now that we have solved two different problems based on perforated panel. So, it gives us a better understanding. So, just like in the case of panel resonators, there was an optimum air depth at which maximum absorption took place and an optimum depth at which minimum absorption took place exactly the same rationale here. So, the absorption will be maximum at the when the cavity depth is lambda by 4 and the absorption will be minimum and cavity depth is lambda by 2.

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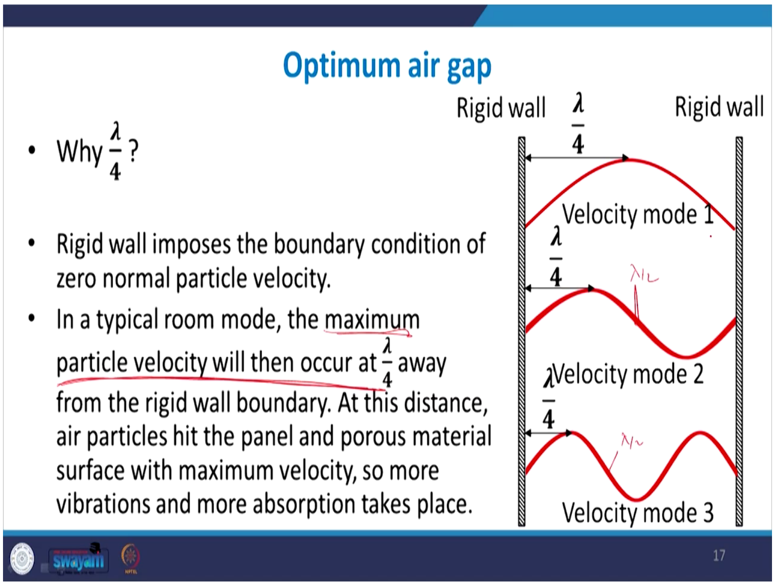

And we have the same explanation that when the panel is being used within a closed room, then the modes of the rooms have generated like this that at every lambda by 4 the particle velocity is the maximum. So, what happens is that the maximum particle velocity occurs at lambda by 4 whenever the modes are set up within a room and because the maximum particle velocity is here.

And this is based on acoustic coupling and the energy being lost by driving the molecules. So, when the sound energy hits the panels with the maximum particle velocity, then large amount of vibrations will be created through and the air molecules around the perforations will vibrate or oscillate had very large amplitudes. So, a stronger resonance will be created and the absorption into the absorption magnitude will increase more and more power will be drawn and very large vibration to induce this large amount of vibration.

So, the same and the same logic is used for lambda by 2. So, the minimum is at lambda by 2; here also at lambda by 2 and then lambda by 2. So, the same logic is used and that is why lambda by 2 where v is minimum. So, here what v is equal to maximum at this particular distance and here v is minimum at this distance and therefore, minimum absorption.

So, v is almost 0 or negligible at that distance then they were whenever the sound energy is hitting at lambda by 2. Then the velocity is not sufficient enough to drive the molecules. So, no resonance takes place ok. Sometimes what is done is that you have a perforated panel and inside the cavity, you filled with porous materials.

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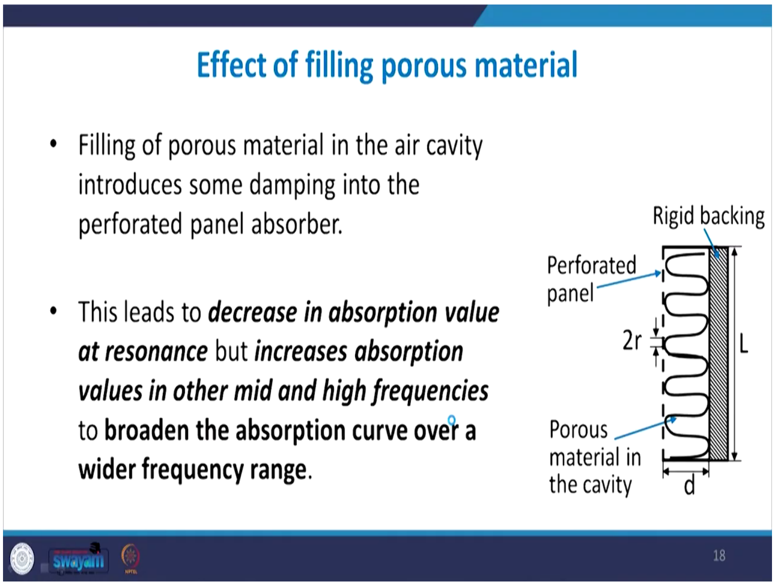

So, what is the effect of the porous material is that we know that such kind of resonators, they only work in a selective frequency. So, as soon as the resonance hits suddenly alpha will jump.

It will reach a peak value and then it decreases. So, very narrow range of high absorption peak is obtained, but we can broaden this range if we fill it with a porous material.

So, when you add a porous material to it, then porous material even at the frequencies other than the resonance they when the sound energies incident. Then there will be no effect of panel, but the porous materials they will do their absorption. So, some absorption will take place at all frequencies due to porous material, but at resonance because the porous material is there.

So, usually at resonance what happens the panel vibrates and the air molecules, they vibrate so much across the panel that it creates large amplitudes and most of the energy incident is lost in doing this work of vibration or oscillation of the particles. But if porous material is added, it sort of hinders this large amount of air molecule oxidations. So, at the resonance slightly the absorption will decrease because of the resistance offered to flow by the porous materials, but at the remaining frequencies the absorption will take place due to the heat dissipation by the porous material.

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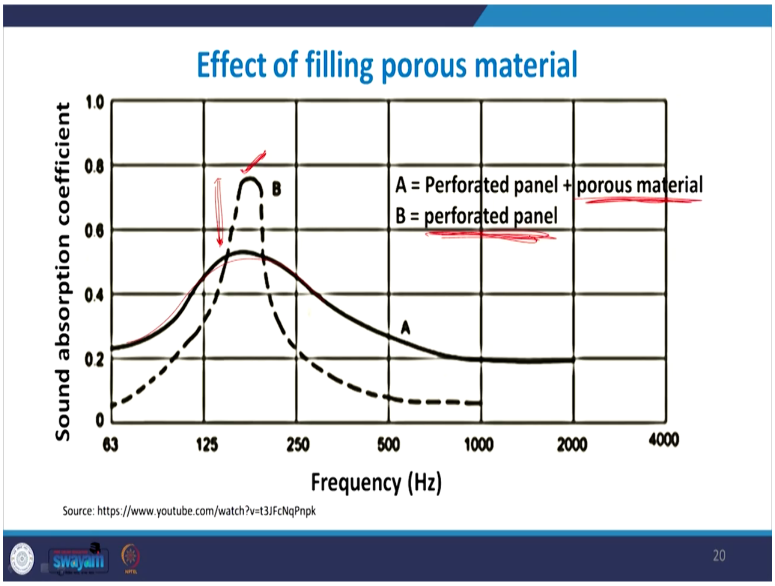

So, in that case this will be a typical curve. So, this is a sharp peak when there is no just a perforated panel and when you add a porous material to it, you get a more broader peak. So, although the intensity absorption intensity is reducing, but the peak is broadening so that is the effect of adding a porous material.

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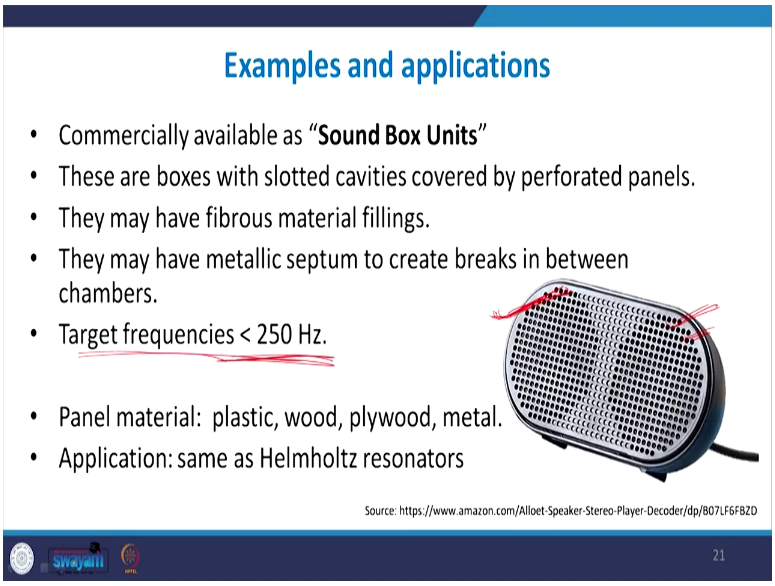

And what are some of the areas where such resonators can be used? Now you have if you have seen you will see that commercially there are lot of sound box units and this figure shows a typical example of a sound box unit.

So, it consists of a cavity or a slot which is covered with some perforated panel and usually they are used as bass killers. So, the target frequencies are smaller than 250 Hertz. So, even if you see the speakers the panel of the speaker looks like this why because to get a clearer sound, we need to reduce the bass or the low frequency noise and this particular thing is like a perforated panel which is trying to reduce the noise that is coming out of it. So, this is a typical example of a commercial usage of perforated panel.

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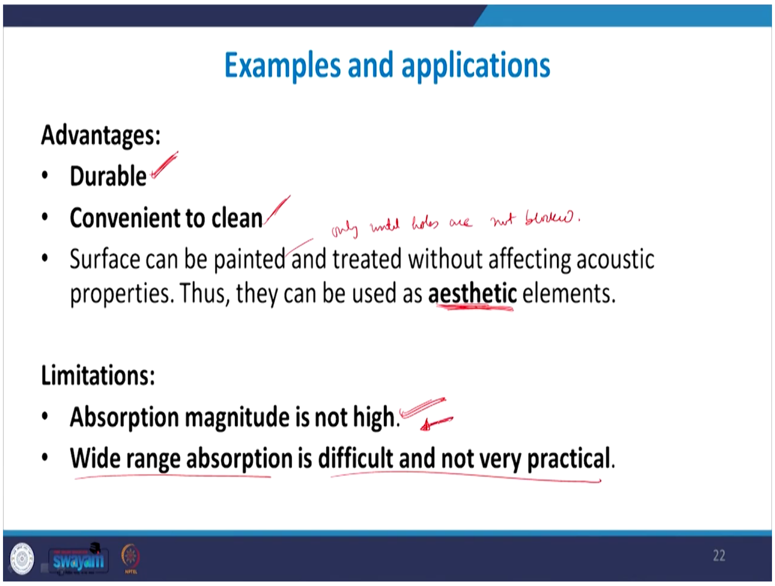

So, a few example advantages and limitations are first of all they are not made of fibers and they are not made of fibers and they cannot be. So, they do not need to be cleaned time and again they are more durable and they are convenient to clean and their surface can be painted.

So, if you paint the surface; they will be aesthetically beautiful, but again in the painting you have to take a caution that the painting should not block the block the perforation. So, it can only be painted only until the holes are not blocked. So, what you can do here is that you already take a painted a painted and shiny looking panel and then you do the perforations and use it inside the rooms. So, it looks good also and it has perforations also. So, it can be used aesthetically.

But the limitations are that the absorption magnitude obtained from this is not very high and wide range absorption is difficult and not very practical because they have very sharp absorption frequency range. So, these are certain advantages and limitations. So, what we saw was that any resonator whether it is a Helmholtz resonator or the panel resonator which is based on the same concept, both of them have a limitation to what is the maximum they can absorb.

And if you go back to the previous lecture you can see what is the limitation or what is the maximum absorption. So, because of this limitation usually even though they can absorb very selectively, but the absorption magnitude is not very high. So, the next set of lectures will be on micro perforated panel. This is a further enhancement or improvement of a perforated panel and they try to they try to cater to this limitation that is a new form of resonator which attains how much higher absorption compared to Helmholtz resonator and panel and perforated panel resonators. So, see you for the next lecture.

Thank you.